FURTHER RESULTS IN DESICCATION AND RESPIRATION OF ECHINOCACTUS

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(WITH ONE FIGURE)

A description of the results of a series of desiccations of *Echinocactus* carried out at this laboratory has been published, in which changes in the water and carbohydrate balance with the accompanying morphological variations were followed in some detail.[1] The experiments were made under two sets of conditions, some of the plants being desiccated in diffuse light within the laboratory, while others were exposed in the open to the full force of the sun and wind. Besides the characteristic features of the water loss, such as its varying rate under different conditions, and the viability of the plants in the face of prolonged desiccation, a number of interesting discoveries were made as to the fate of the carbohydrate nutriment of the desiccated plants. It was found that Echinocacti drying in the open stored carbohydrate at a rate exceeding its loss, a large portion of the increase taking place in the "soluble nonreducing sugar" fraction (including cane sugar); and that in long desiccation in diffuse light oxidation of the stored sugars took place at such a rate that the dry weight of the plant tissue remained constant, as large a proportion of water being found after 6 years of desiccation in the case of one plant as was present in the beginning, in spite of a loss of nearly 30 per cent of its original weight by water depletion. These results were very striking, and it seemed that it would be of unusual interest to combine these effects in one plant, thereby obtaining new light on the course of katabolism in the various types of carbohydrate and on the time element involved.

Accordingly, an *Echinocactus* which had been loaded with carbohydrate by desiccation in the open, after 8 months was placed in a ventilated dark chamber where photosynthesis was no longer

[1] MACDOUGAL, D. T., LONG, E. R., and BROWN, J. G., Physiological Researches, no. 6, August, 1915.

possible and katabolism would go on without extensive repair. No. 23 of the series referred to was chosen for this purpose, because in treatment, appearance, and amount of water loss it was comparable to no. 22, a plant desiccated in the open, the analysis of which has been recorded. It is entirely probable that in the composition of its tissues no. 23 when put into darkness was similar to no. 22 at the time of its analysis, that is, was characterized by a high content of the sap in soluble non-reducing sugars. The results of the analysis of no. 23 after 22.5 months in darkness are given in table I, in which the corresponding analyses for nos. 7, 22, and 34 are quoted from the article already referred to for comparison. Although it had lost 57 per cent of its original weight in the entire course of its desiccation (12 per cent after it was put in darkness), when removed from the dark chamber it was still of healthy appearance, green at the apex, and only slightly yellowed along the apices of the spiny ridges, and MACDOUGAL ventures the statement that it would have put out new roots had it been returned to the soil in such condition at the proper season.

TABLE I

RESULTS OF ANALYSES OF TISSUES OF *Echinocactus*

Analyses made	No. 23; desiccated in full sunlight 8 months, 10 days and in darkness 22 months, 17 days; total water loss 57.2 per cent		No. 7; desiccated in diffuse light 6 years, 1 month; total water loss 29.3 per cent			No. 22; desiccated in full sunlight 5 months, 6 days; total water loss 40 per cent			No. 34; normal, not desiccated		
Tissue sample	ab	c	a	b	c	a	b	c	a	b	c
Dry weight per cent of total weight	20.2	17.1	9.5	8.0	5.8	14.3	13.3	11.3	5.8	4.2	3.6
Sap density (water = 1.00)	1.018	1.035	1.010	1.018	1.013	1.016	1.027	1.034	1.013	1.011	1.011
Sap acidity, N/10	0.600	0.400	0.144	0.104	0.148	0.244	0.208	0.156	0.172	0.156	0.128
Total hydrolyzable carbohydrate; per cent of total solids	31.5	28.2	22.3	24.2	11.1	44.3	44.2	43.4	32.3	35.7	29.6
Total reducing sugars; per cent of total sap weight	0.08	Trace	0.09	0.06	0.04	0.15	0.13	0.10	0.53	0.42	0.10
Total non-reducing sugars; per cent of total sap weight	Trace	Trace	0.11	0.10	0.06	1.28	1.48	2.67	0.14	0.03	0.05

In table I, *a*, *b*, and *c* represent certain arbitrarily defined tracts in the cortex of the plant, *a* and *b* (joined in the case of no. 23) including the white pulp within the spiny ridges, *a* being the outer sample taken from the area just under the cuticle, *b* being just interior to *a*, while *c* represents the great body of the deeper pulp and is characteristic of nine-tenths of the cortical tissue. The sugar analyses were made with Fehling's solution, calculations being made in terms of dextrose. Reducing sugars were determined by direct titration of the neutralized sap, soluble non-reducing sugars similarly after one hour's hydrolysis of the sap on the water bath with 10 per cent HCl, and total hydrolyzable carbohydrates of a given weight of tissue after 4 hours' hydrolysis with 5 per cent HCl. The last term thus covers all substances which break up with 5 per cent HCl to give reducing sugars, consisting in this instance of a variety of polysaccharides, including pentosans and probably hemi-celluloses as well as starch, besides the soluble sugars. In a rough way it measures the stored nutriment of the plant. A more detailed description of the methods used is given in the previous article.

The results of the observation of no. 23 and of its final analysis are shown in fig. 1 and table I, and the conclusions to be drawn from them may be summarized briefly as follows. As would naturally be expected, the curve of water loss shows a distinct break at the point where the plant was transferred from the rigorous conditions of the laboratory court to the more equable conditions of the dark chamber. A more interesting finding is the uniformity of the rate of the water loss, which, in the already well desiccated plant, seemed almost independent of seasonal changes. Small variations did indeed occur, but they cannot be well shown on the scale of the accompanying tracing. Inasmuch as the temperature variations of the surrounding air must have been large, the dark chamber being located in an unheated portion of the laboratory building, the strong influence of light upon evaporation is shown, for very noticeable seasonal changes in evaporation were observed in other plants drying at fairly equable temperatures even in the diffuse light of the laboratory.

Several distinct changes have taken place in the sugar concentration. A high acidity is noted, which is explained by the conditions of the plant's confinement. It has been repeatedly brought out at this laboratory that the oxidation of the organic acids resulting from sugar katabolism is more rapid in the presence of light, and that these acids tend to accumulate in darkness. Soluble sugars in no. 23 have been burnt out almost completely, only traces being found in the expressed sap. If, as we have assumed, a high

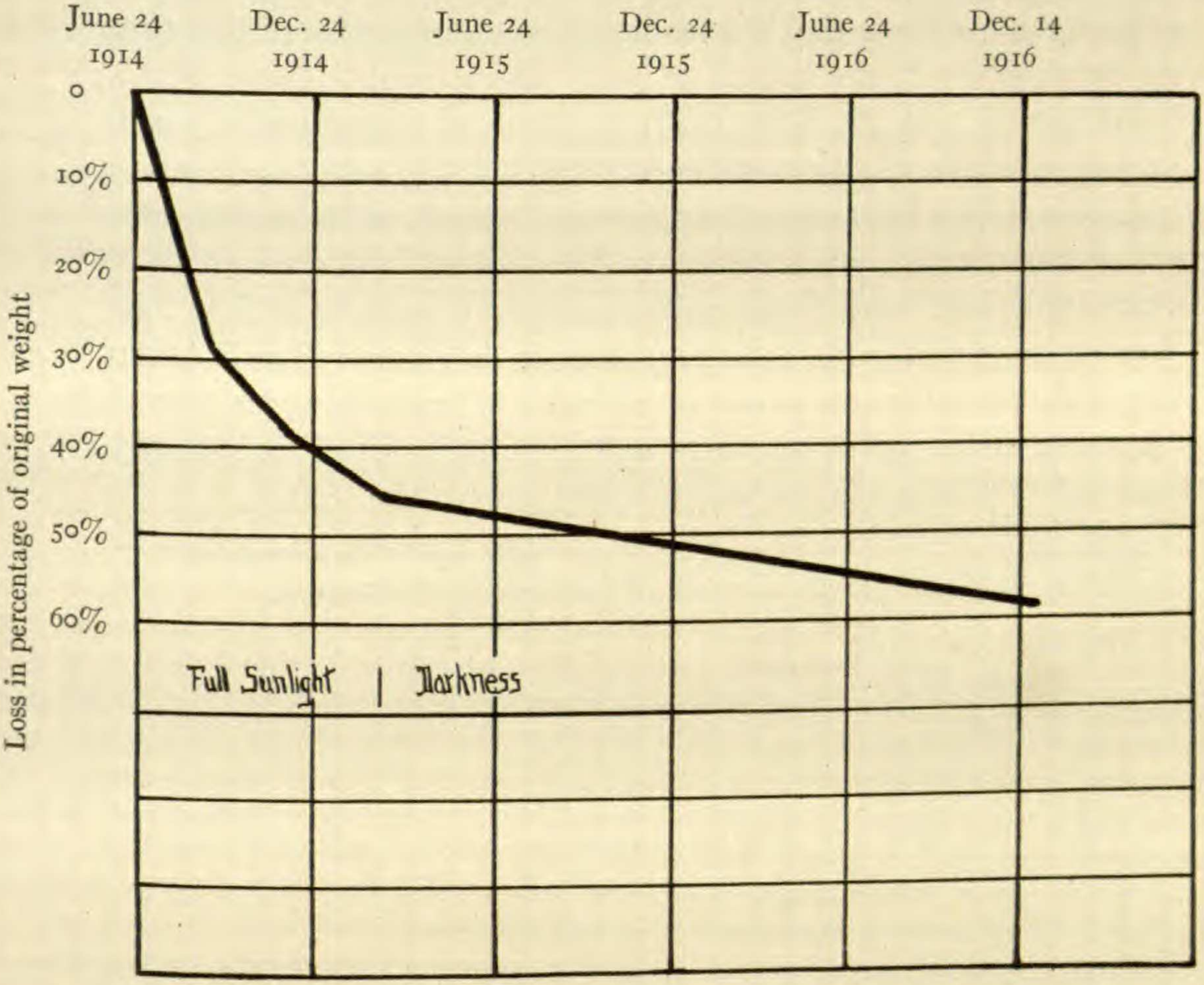

FIG. 1.—Illustrating course of loss in weight of *Echinocactus* no. 23 from June 24, 1914, to January 23, 1917.

concentration of soluble non-reducing sugars was present in the sap of no. 23 at the time when it was put into darkness, a very large destruction has taken place of sugars of this type. However, and this is an important point, the destruction of the stored insoluble polysaccharides seems hardly more than begun. A consideration of table I shows that the total hydrolyzable carbohydrate content of no. 23 after its prolonged stay in darkness is hardly less than that of the normal, no. 34, and while it is lower than that recorded for no. 22, it must be remembered that the high figure for total hydrolyzable carbohydrates in no. 22 is due in a large measure to the high concentration in the pulp of soluble non-reducing sugars, the term "total hydrolyzable carbohydrates," as defined, covering hydrolyzable carbohydrates of all types, soluble and insoluble. On the other hand, we know that the insoluble polysaccharides of this type do break down in the course of long confinement without photosynthesis; witness the difference in the figures for total hydrolyzable carbohydrate in the case of the normal, no. 34, and no. 7, which rested in diffuse light more than 6 years. Much of the polysaccharide content of no. 7 has evidently disappeared in the course of its starvation; yet what happened to no. 7 in 6 years in diffuse light has not happened to no. 23 in 22 months in darkness. The breaking up of the stored insoluble polysaccharides in response to the plant's demands on its source of energy evidently takes place very slowly, and this fact, taken in conjunction with that of the resistance of the Echinocacti to desiccation, helps in a large measure to explain the viability of these plants in spite of prolonged starvation.

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